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# The Flow of Water In Earth Channels

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# THE FLOW OF WATER IN EARTH CHANNELS

BY

EDWARD JAMES FUCIK

THESIS

FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
1901

F95

UNIVERSITY OF ILLINOIS

May 29, 1901

This is to certify that the thesis prepared under the direction of Professor Talbot by

EDWARD JAMES FUCIK

entitled THE FLOW OF WATER IN EARTH CHANNELS

is approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

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Head of Department of Civil Engineering

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# The Flow of Water in Earth Channels

Galileo, who, at the beginning of the seventeenth century, discovered the laws of falling bodies, declared he had "found less difficulty in the discovery of the motions of the planets in spite of their amazing distances, than in his investigations of the flow of water in rivers, which took place before his very eyes."

During the last century, works on hydraulics have been published which throw some light on the laws of the motion of water in rivers and canals. Among such published works are the "Recherches Hydrauliques" of D'arcy and Bazin, the work of Kutter and Ganguillet, and its translation and development by Rudolph Hering, and the "Theory of the Motion of Water in Rivers

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and Canals" by Humphreys and Abbot. Each work proposes a new formula which differs not only from each other but also from the previous formulas of Prony, Chezy, St. Vincent, Eytelwein and others. The formulas of Dárcy and Bazin were derived from observations on small rivers and canals, and that of Humphreys and Abbot from observations on very large rivers like the Mississippi. Neither can have a general application, as the former is inapplicable to large rivers with low inclination and the latter to small ones with greater fall. Perhaps the formula most used and the one giving the greatest satisfaction is that of Kutter, a Swiss engineer.

The wide variation in discharges computted by different formulas is well illustrated by Vincent, who takes an example from Patzig's Praktische Rieselwirth. The latter gives a discharge of 30 cubic feet per second for a case which, according to Eltelwein is 66 cu ft. and accord- to Ganguillet and Kutters general formula is 64 cu. ft. using n = 0.030. This shows a variation of 35% from the mean of the results.

In 1899 and 1900, Messrs Slocum and Appelquist of the class of '00, of the the University of Illinois, made a series of observations on the flow of water in earth channels or drainage ditches, such as are commonly found throughout Central Illinois, with a view of determining a general formula for the flow. As the formula for the flow of water must be largely empirical and as there cannot be one for every case, the need of such a general formula can readily be appreciated. The writer has taken for his thesis work a continuation of the work of Messrs Slocum and Appelquist. The formulas for the flow in channels ordinarily used will be briefly considered before taking up the observations and results of the writer.

## Formulas for Flow.

There are various formulas in use but the most common are those of Chezy, D'arcy and Bazin, and Kutter. That of Humphreys and Abbot was intended to be adapted to streams of small slope and therefore cannot have a general application. Recent developments however discredit their results.

Chezy's well known formula is $V = C\sqrt{RS}$ in which

$V$ is the mean velocity,

$R$ is the hydraulic radius,

$S$ is the inclination of the water surface and $C$ is an experimental coefficient. It was assumed that this formula gave correct results for all cases and conditions of inclination and dimension, a fallacy which vanished only after a long time with the discovery that the coefficient $C$ is not a constant, but a variable quantity.

In a letter to Messrs Slocum and Appelquist, Mr. Clarence Johnson, assistant in the irrigation Investigation, suggests a formula of the same form as Chezy's. It is, $V = C'\sqrt{\frac{a \times f \times 5}{p \times 3}}$

in which

$a$ is the area of flow,

$f$ is the fall in feet per mile,

and $p$ is the wetted perimeter.

He states that this has been generally adopted by irrigation engineers in the West.

In the "Recherches Hydrauliques" of D'arcy and Bazin in 1865 the coefficients c are made to vary with the values of the hydraulic radius R and the conditions of the sections. These are classified into four categories having a formula for each but which do not include every degree of roughness. They derived their formulas from experiments made on an artificial canal, two meters wide and one meter deep, about six hundred feet long, of different sections, and whose banks were made of different materials. The sections were, rectangular, trapezoidal polygonal and circular. The observations of D'arcy and Bazin indicate that the degree of roughness of the wetted perimeter exerts an important influence on the value of the coefficient on small sections of discharge.

In 1867 Ganguillet and Kutter made several experiments on semi-circular artificial channels to determine the variation of c, and observed that it increased with an increase of R, decreased with the slope S and decreased with an increase of the roughness. They assumed that the velocity

varied as the square root of the slope S and adopted Chezy's form of formula $V = C\sqrt{RS}$ but proposed a formula for the coefficient C, which varied with the slope, hydraulic radius and the degree of roughness. The formula for C is.

$$C = \frac{\frac{1.811}{n} + 41.65 + \frac{0.00281}{S}}{1 + \left(41.65 + \frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

in which n is a value differing for various degrees of roughness, R is the hydraulic radius and S is the slope or sine of the inclination. They tabulated the values of n for different degrees of roughness, which vary from 0.010 for channels lined with carefully planed boards or smooth cement to 0.035 for channels in bad order having a very rough surface. Ganguillet and Kutter's general formula is perhaps the most widely used on account of its adaptability to various conditions.

Messrs Slocum and Appelquist's observations were satisfied by a formula of the form $V = 50r\sqrt{S}$ in which V varies directly as R, but it is thought that this is not of general applicability. Their observations cover a range of R of 1.35 feet and they concluded that n of Kutter's formula covers more than the minute surfaces of contact.

## The Writer's Observations and Data.

The observational work carried on by the writer was done in essentially the same manner as that of Messrs. Slocum and Apelquist in 1900.

Observations were taken on the Great Beaver Branch, an artificial drainage ditch which crosses the Illinois Central Railroad a quarter of a mile north of Leverett and flows into the main drainage ditch, the Great Beaver, three-quarters of a mile east of the railroad, and on the East Lake Fork, a similar ditch which has its source about one quarter of a mile west of Bondville and joins the main stream about a mile west of Ivesdale. The gauging station was about 1000 feet north of the Wabash Railroad and 2¼ miles east of Ivesdale. The total drainage area of the water shed drained is about 17000 acres, of which about 15000 acres is above the gauging station. This ditch was widened and deepened in the summer of 1900 so that it was of uniform cross-section and very free from weeds.

The gaugings were made with a Fteley and Stearns current meter manufactured by Buff and Berger, belonging to the Department of Theoretical and Applied Mechanics. The velocities in feet per second were taken from a diagram prepared by Mr. Slocum, in which the velocities in feet per second were plotted as abscissa: and the number of revolutions per minute as ordinates.

The method used to determine the mean velocity of the section was as follows:— At the Great Beaver Branch a tape was stretched across the ditch, and at the East Lake Fork the tape was laid along a foot-bridge over the gauging station. Meter readings were taken at points two feet apart horizontally across the stream. At each of these points the meter was slowly lowered from the surface of the water to the bottom of the channel and back to the surface several times during each observation. Each gauging was one minute in duration. Two gaugings were taken at each point. The cross-section of the stream was divided up according to the points gauged and the areas of the various sections com-

puted and the quantity of water passing thro, then found. The total quantity of water passing the cross-section equals the sum of the quantities passing each section. The mean velocity equals the quantity of water passing the cross-section, divided by its area. Gaugings were made at three stages of water for each of the channels observed.

Cross-sections of the channels were found by streetching a chesterman tape across and measuring the distance from the tape to the bottom of the channel with a level rod. The slopes of the bottom of the channel and the water surface were obtained by taking level reading every 250 feet on the Great Beaver Branch and every 500 feet on the East Lake Fork.

The cross-sections of the water way of the East Lake Fork below and above the gauging station run very uniform as is shown by the following areas calculated for a depth of two feet of water for stations 0, 13 and 13.

Station 0, Area = 23.5 sq ft.
" 8, " = 22.8 " " gauging station.
" 13, " = 21.4 " "

The greatest variation from the mean is 6%.

Two cross-sections only, of the Great Beaver Branch were taken. The areas computed for a common water depth of two feet are as follows:–

Station 0, area = 20.33 sqr. ft. Gauging Sta.
" 2, " = 18.94 " "

The variation here is 3%.

To make a comparison of the results it was assumed that for such channels, within the range of slopes used, the velocity will vary as the square root of the slope. The form of formula $V = C R^m S^{\frac{1}{2}}$ was assumed, since that is closely similar to the function given by Kutters formula and other formulas for flow in channels. By plotting the logarithms of the velocities minus one-half the logarithms of the slope, as ordinates, and the logarithms of the hydraulic radii as abscissae, the equation of a line drawn through these points can easily be determined. This equation would be a general one for the flow in a given channel. The results of the gaugings and the equations of the lines derived from the plotted points are shown on Plate V. The difference in the roughness of the channels of the two ditches

is, shown by the two lines, that for the East Lake Fork being above that for the Great Beaver Branch. The formula derived for the flow of the East Lake Fork has the equation $V = 60 R^{0.7} \sqrt{S}$ and that for the flow of the Great Beaver Branch has the equation $V = 35 R^{0.7} \sqrt{S}$.

The writer was informed by a resident, that the depth of flow in the East Lake Fork has not exceeded six feet since it was cleaned and has calculated the discharges for that depth.

By Kutter's formula the dicharge = 546 cu. ft. per sec.
" $V = 60 R^{0.7} \sqrt{S}$ " " = 569 " " "

The latter result is about 22% of that given by Fanning for flood flows for areas drained.

The results of the observations of the East Lake Fork and Great Beaver Branch are shown in Table I. The method of recording gaugings is shown in Table II and the levels for the slopes of the water surfaces and bottoms of the channels are shown in Table III. Plates I, II, III, and IV show cross-sections of the channels of the two ditches. The agreement of the two formulas with Kutter's for $n = .025$ and $n = .035$ is shown by Plate VI.

## Conclusion

Kutter was among the first to recognize the erroneous nature of previous hydraulic formulas and realizing that the relation $V = C\sqrt{RS}$ may well be retained as the fundamental expression endeavored, with Ganguillet, to establish laws for its variation. How well they succeeded is shown by the general adoption of their formula for c. However, owing to its unwieldy nature and to the difficulty in choosing the proper value of n, the coefficient for the degree of roughness of the channel, the generalization of the variation of c or any information for choosing the value of n, is seen to be of very great importance.

From the data herewith presented, together with those available for comparison, it may be seen that the value of n for the flow in drainage ditches is largely dependent upon the size of the channel and upon its condition. A well constructed channel, newly dug or recently cleaned, gives a much larger flow than one having the inequalities of bottom and section which the wash of land and the deposit of silt and the uneven growth

of vegetation give. Weeds and other obstructions increase the roughness and impede the flow. It is also apparent that at shallow depths the inequalities of cross-sections are greater and have an even greater effect on the velocity than is the case for considerable depths of water. Taking these matters into consideration, it may be concluded that for clean, well-formed ditches with flows greater than one foot in depth a value of Kutter's n equal to .025 may be used for calculating the velocity, and that for ditches of unequal section having deposits and washed banks a value of from .030 to .040 should be used. A formula with the variable c generalized, would be better and more easily used than Kutter's. For the condition of the two ditches gauged, $V = 60R^{0.7}\sqrt{S}$ and $V = 35^{0.7}\sqrt{S}$ give results approaching the actual flow.

The writer regrets that, owing to little rainfall and unfavorable conditions, fuller data and more definite conclusions cannot here be presented.

# TABLE I.

Showing results of observations on East Lake Fork and Great Beaver Branch.

| Name of Ditch. | Depth of Flow. Feet | Area of Section. Square feet | Wetted Perimeter in feet. | Hydraulic Radius. Feet | Velocity in feet per second | Discharge in cubic feet per second. | Sine of the slope. | Coefficients | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | n | c |
| EAST LAKE FORK | 2.92 | 38.50 | 20.048 | 1.92 | 2.02 | 77.81 | 0.000484 | 66 | 0.024 |
| | 1.74 | 18.67 | 16.056 | 1.16 | 1.24 | 23.15 | 0.00040 | 57 | 0.025 |
| IVESDALE | 1.52 | 15.14 | 14.960 | 1.09 | 1.08 | 16.40 | 0.00030 | 60 | 0.023 |
| GREAT BEAVER BRANCH | 3.90 | 58.86 | 23.028 | 2.55 | 1.86 | 109.59 | *0.00075 | 43 | 0.039 |
| | 2.46 | 23.42 | 20.220 | 1.16 | 1.10 | 26.94 | *0.00080 | 36 | 0.037 |
| LEVERETT. | 1.46 | 12.44 | 13.416 | 0.93 | 1.22 | 15.26 | 0.00096 | 41 | 0.033 |

* Slocum and Appelquist's value of slope.

# Table II.

## Sample Table

## Showing Method of Recording Gaugings.

Height of water = 2.92 feet.

| Distance out in feet | Time. | Beginning of reading. | End of reading | Number of revolutions | Mean | Velocity in feet per second. |
|---|---|---|---|---|---|---|
| 12 | 1 min. | 169 | 265 | 96 | 92.4 | 1.52 |
| | | 146 | 238 | 92 | | |
| | | 235 | 324 | 89 | | |
| 14 | 1 " | 265 | 389 | 124 | 118 | 1.96 |
| | | 238 | 358 | 115 | | |
| | | 324 | 439 | 115 | | |
| 16 | 1 " | 389 | 527 | 138 | 136 | 2.28 |
| | | 899 | 35 | 136 | | |
| | | 39 | 173 | 134 | | |
| 18 | 1 " | 832 | 969 | 137 | 141.6 | |
| | | 545 | 686 | 141 | | |
| | | 752 | 899 | 147 | | |
| 20 | 1 " | 686 | 832 | 146 | 135 | 2.25 |
| | | 623 | 752 | 129 | | |
| | | 854 | 984 | 130 | | |
| 22 | 1 " | 969 | 09 | 121 | 128.3 | 2.15 |
| | | 485 | 623 | 138 | | |
| | | 737 | 863 | 126 | | |
| 24 | 1 " | 109 | 210 | 101 | 103.6 | 1.72 |
| | | 381 | 485 | 104 | | |
| | | 347 | 453 | 106 | | |
| 26 | 1 " | 210 | 297 | 87 | 82.3 | 1.35 |
| | | 04 | 80 | 76 | | |
| | | 297 | 381 | 84 | | |

## Table III.

### Levels for slopes of East Lake Fork and Great Beaver Branch.

| Station | B. S. | H. I. | F. S. | Elev. | B.M. | Remarks. |
|---|---|---|---|---|---|---|
| | | | | | 50.0 | |
| | 2.583 | 45.793 | | | | |
| 0 | | | 4.427 | 40.766 | | H.W. april 17. |
| " | | | 5.767 | 39.426 | | B.D. " " |
| 3 | | | 4.957 | 40.836 | | H.W. " " |
| " | | | 6.479 | 39.314 | | B.D. " " |
| 8 | | | 4.827 | 40.966 | | H.W. " " |
| " | | | 6.347 | 39.446 | | B.D. " " |
| " | | | 3.427 | 42.366 | | HW March 26. |
| ⊙ | 2.073 | 45.283 | | 43.210 | | |
| 13 | | | 2.675 | 42.608 | | H.W. " " |
| " | | | 4.207 | 41.076 | | H.W. april 17 |
| " | | | 5.773 | 39.510 | | B.D. " " |
| ⊙ | 4.702 | 47.316 | | | 42.608 | |
| 18 | | | 6.009 | 41.301 | | H.W. " " |
| | 0.44 | 50.44 | | | 50.0 | Great Beaver Branch |
| ⊙ | | | 5.889 | 44.551 | | |
| 0 | 4.523 | 49.074 | | | | |
| 0 | | | 7.754 | 41.320 | | BD. april 12. |
| " | | | 6.290 | 42.784 | | H.W. " " |
| " | | | 3.847 | 45.227 | | H.W. March 25. |
| 2+50 | | | 8.036 | 41.038 | | B.D. april 12. |
| " | | | 6.529 | 42.545 | | H.W. " " |
| 5 | | | 7.993 | 41.081 | | B.D. " " |
| " | | | 6.671 | 42.403 | | H.W. " " |

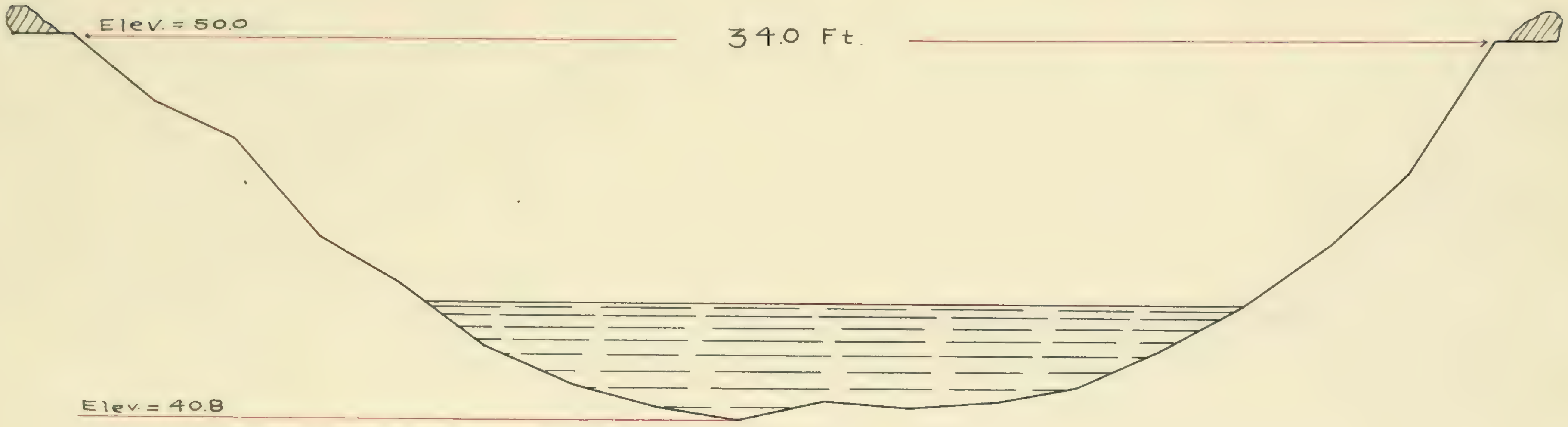
H.W. = height water.
B.D. = bottom Ditch.

# PLATE I.

## CROSS-SECTION OF EAST LAKE FORK

Station O

Scale – 4 feet per inch horizontally and vertically.

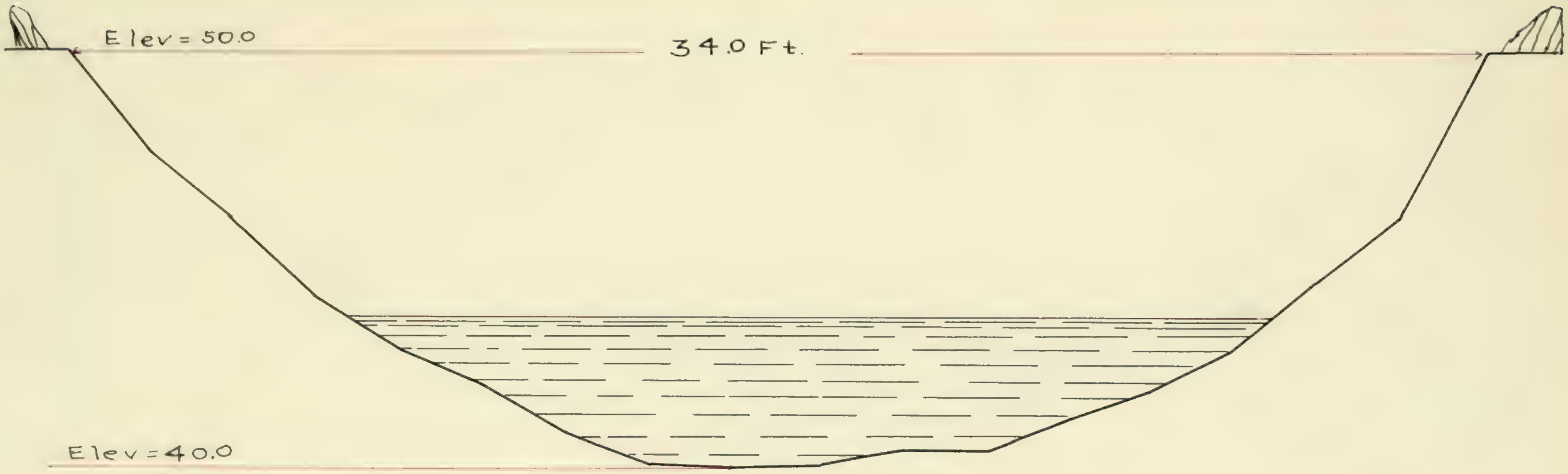


# PLATE II.

## CROSS-SECTION OF EAST LAKE FORK

Station 8

Scale – 4 feet per inch horizontally and vertically

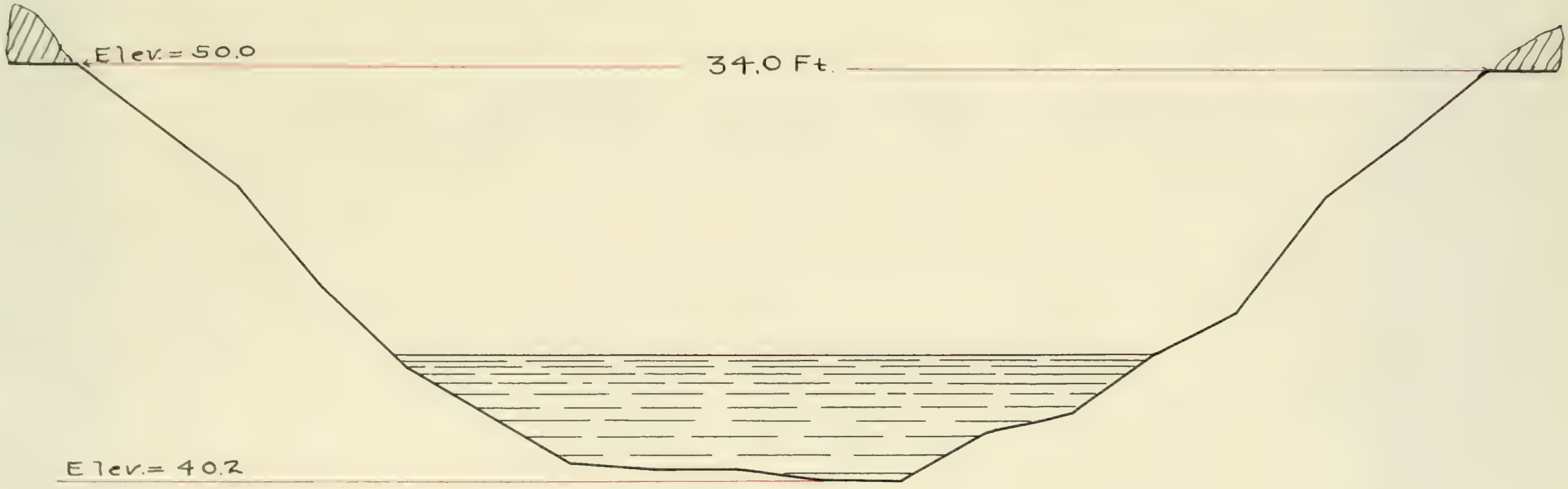


# PLATE III.

## CROSS-SECTION OF EAST LAKE FORK

Station 13

Scale-4 feet per inch horizontally and vertically.

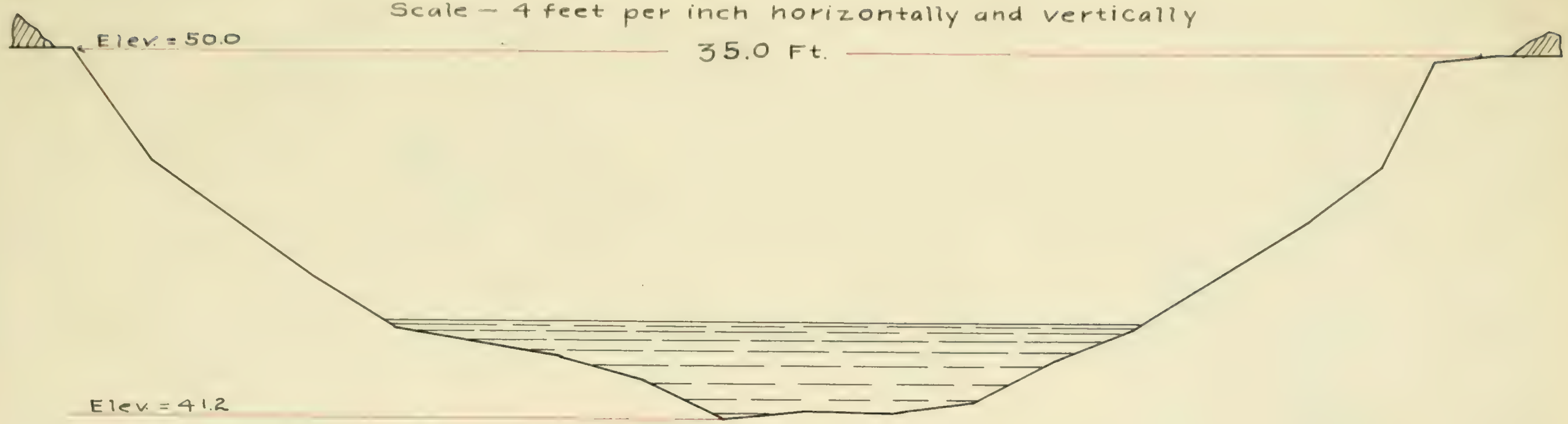


# PLATE IV.

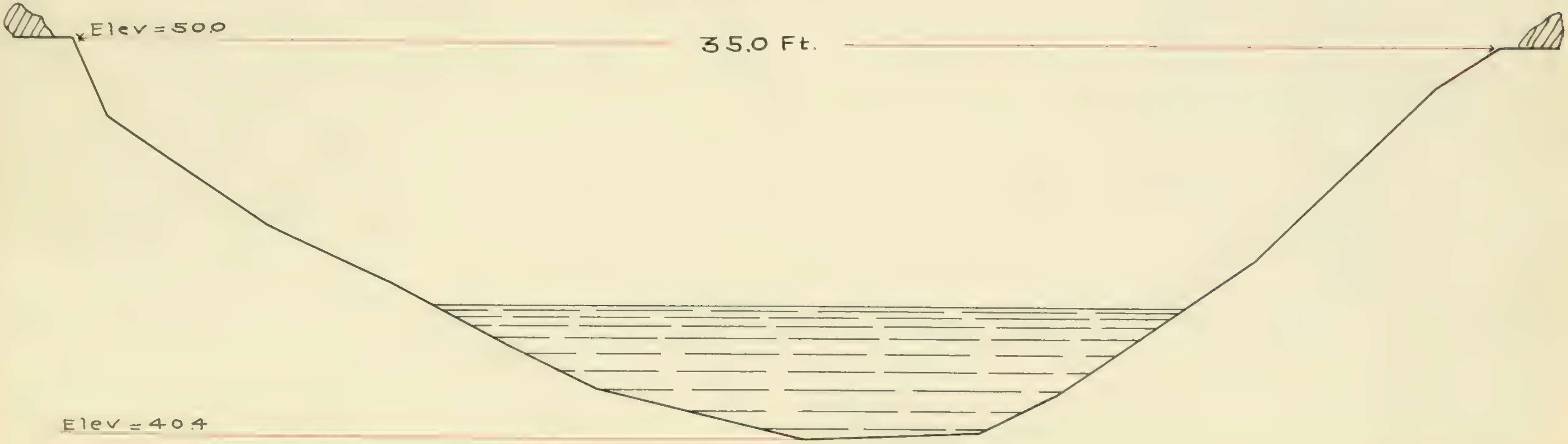
## CROSS-SECTIONS OF GREAT BEAVER BRANCH

Station 0.

Scale – 4 feet per inch horizontally and vertically

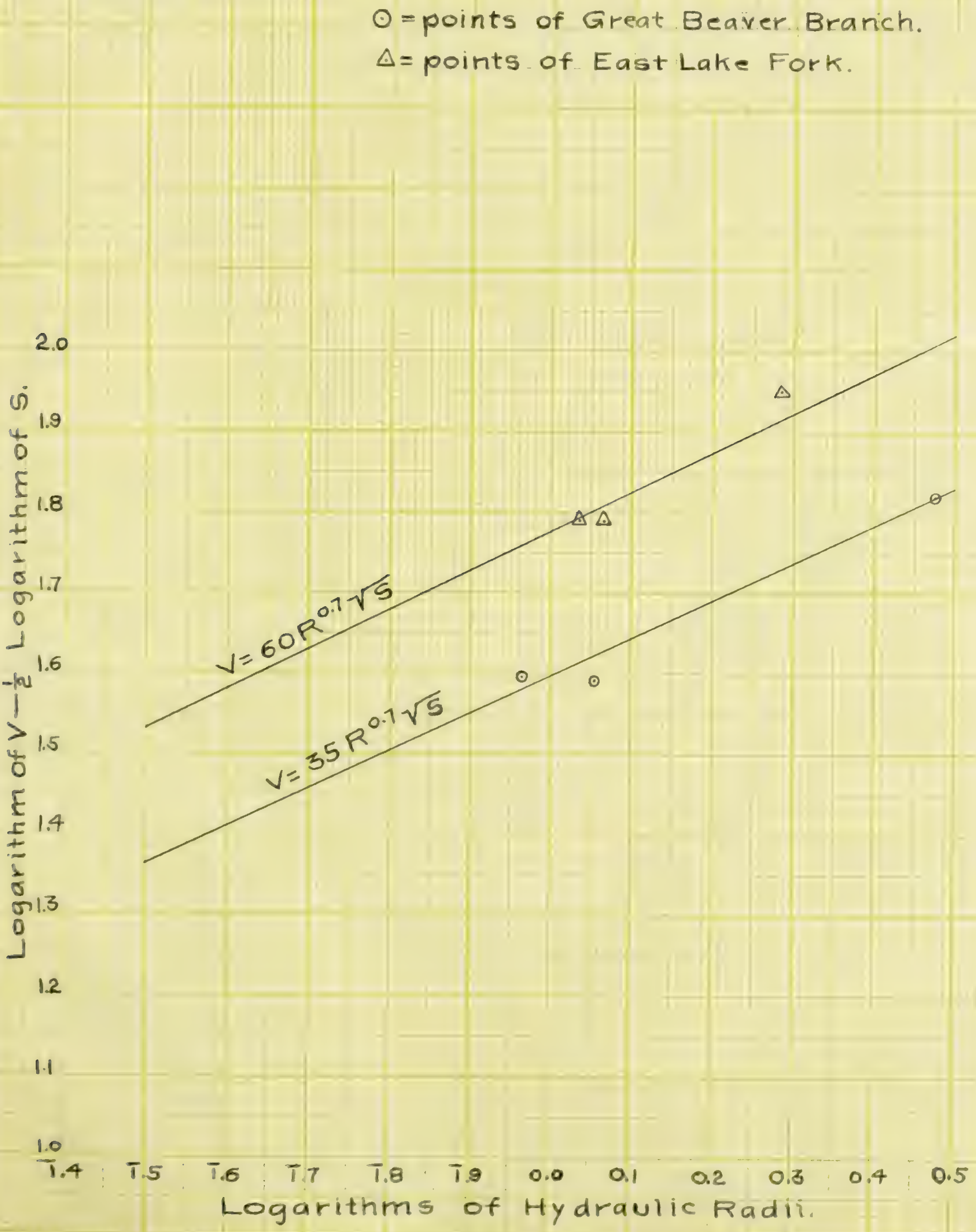


Station 2.



# PLATE V.

Diagram showing relation between hydraulic radius and velocity assuming that V varies as $\sqrt{S}$.

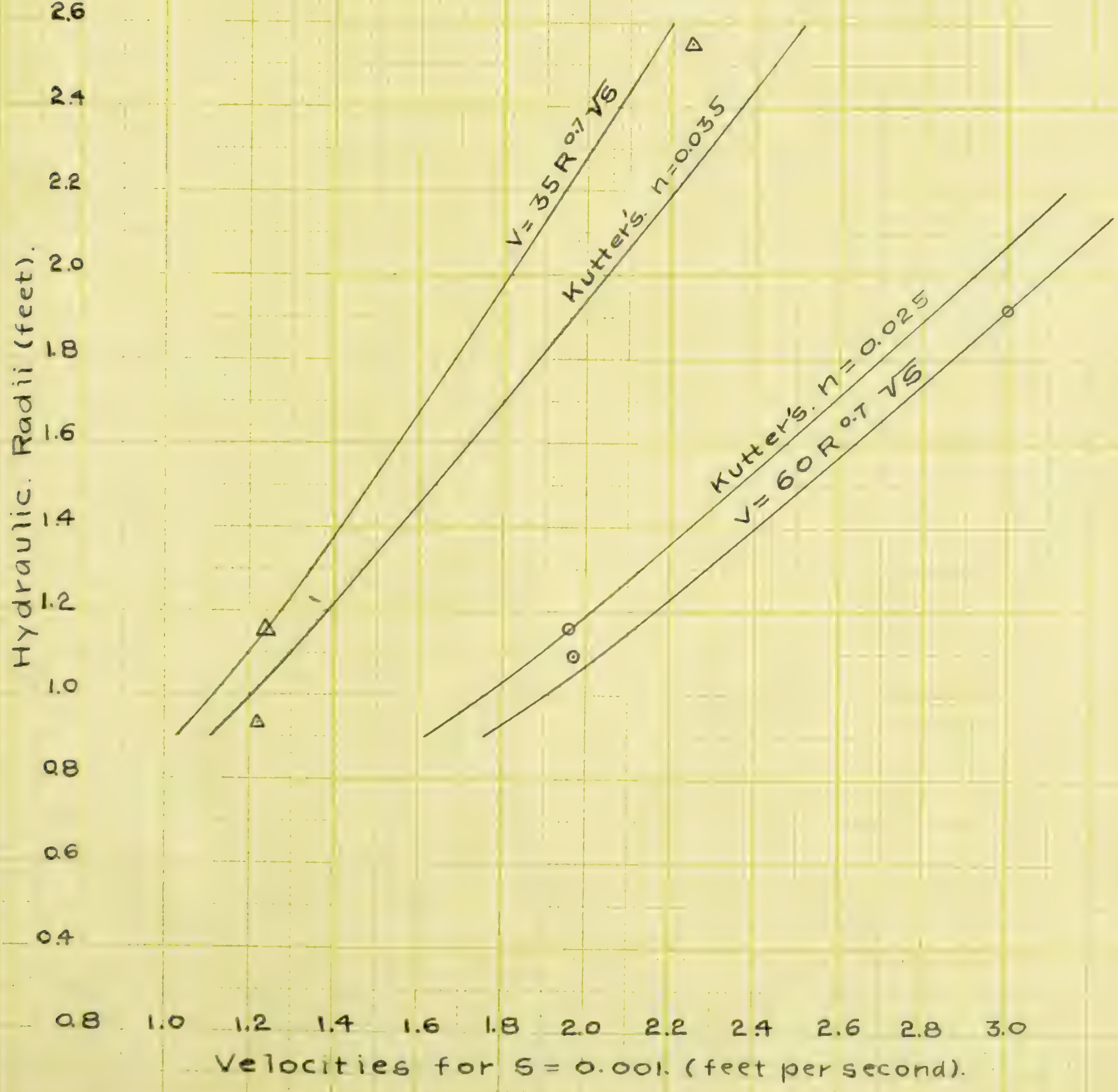


# PLATE VI.

Diagram showing a comparison of observered values with Kutter's formulas.

△ = points of Great Beaver Branch.

⊙ = points of East Lake Fork.



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